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Technical Report **R 408**

POTABLE-WATER-SHORTAGE SURVEY

October 1965

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

POTABLE-WATER-SHORTAGE SURVEY

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Type C

by

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ABSTRACT

Present and predicted potable-water shortages at naval shore stations were surveyed to obtain information relating station water requirements to the growing national and worldwide concern over water availability. For this survey, a lack of conventional fresh-water sources and unreasonable costs for water procurement and production constitute a shortage. Current water problems were found to exist primarily at overseas facilities on small islands or in unfavorable coastal locations. Polar areas have a continuing water problem with high water-production costs, resulting in a number of subsidiary problems in polar-base operations. Within the continental United States, there are a number of large stations located in regions where overall water deficiencies are expected to occur by 1980 or 2000. The major problem areas are Southern California and the Texas southern Gulf Coast. A survey of water quality was also made, and corrosion, scale, and high concentrations of deleterious minerals were the most significant problems not responding to conventional treatment. It is recommended that a further study be initiated to develop improved methods for solving the water-quality problems.

The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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INTRODUCTION

Adequate supplies of potable water are necessary for the effective function of all naval stations. This report covers results of a survey intended to discover where in the Shore Establishment shortages of potable water are likely to occur and to define the extent of the problem. The task was proposed and sponsored by Code 63.300 of the Bureau of Yards and Docks, with the provision that both the current situation and a projection to 1980 be considered.

The term "potable water" is used somewhat more widely in the Navy than in municipal practice, to distinguish the potable system from the impure seawater systems used around dock areas for other than drinking purposes. Since typical municipal water supplies use only potable water for all purposes, the adjective "potable" is not usually applied in describing their water supplies.

Until recently, the principal problems concerning water supplies for shore stations involved mainly overseas stations on small islands, and there the problem was minimal, because "field" conditions, with relatively low water requirements, would usually be expected to prevail at such stations. Currently, however, the problem at such stations is increased, because many island stations are now permanent, with increasing levels of water consumption brought on by family housing and somewhat higher standards of living for all personnel. At the same time, there are a number of areas within the United States that are expected to have general water-shortage problems that may result in limited supplies for all users in those areas. Increasing populations in those areas will use more and more of available supplies, causing higher prices and lower availability of undeveloped conventional supplies.

NAVAL STATION WATER REQUIREMENTS

Water requirements at naval stations vary widely with the station function and location. Large, permanent, stateside stations with extensive family housing are sizable cities with all the normal municipal requirements, including industrial demands. If the station is located in a very warm region, heavy demands for cooling water and landscape irrigation may exist. Consequently, the station use is frequently in the range of 100 to 200 gallons per capita per day. This requirement may be met in several ways. If the station is isolated from population centers, it usually will have its own sources and treatment system. If it is a part of a large metropolitan area, water is usually purchased from a civil water system, but the station may have

its own distribution system, including pumps, fire reservoirs, and distribution reservoirs. The use of seawater at stateside stations is usually limited to dockside fire emergency systems.

Overseas station water demands are likely to be lower than stateside, with lower proportions of family housing and less industrial use. Typical planning estimates are 50 gallons per capita per day for normal conditions and 25 gpd for austere conditions. Hospital components are allotted 100 gpd. Data received during the survey indicated levels of consumption higher than the planning estimates and almost as high as stateside bases in some cases. The basic supply source is more likely to be operated entirely by the station, but in many areas, water is obtained by agreement with the civil authorities in the country where the station is located. Rain catchment and distillation are used on several islands. Seawater is ocasionally used for fire systems throughout the stations and may also be used for toilet flushing and other uses not requiring potable water.

WHAT IS A WATER SHORTAGE?

The question of defining what is meant by a "water shortage" must be answered with some accuracy before a useful survey of shortages can be made. Water tends to be used like money: the more there is available, the greater the rate of use will be. Most widely published popular and semitechnical literature tends to describe shortages in terms of a predicted inability to fulfill all the most desirable requirements for a certain population level at some time in the future. Water requirements of Navy shore stations must center on military function first, but economic and technical considerations are also an important part of the water-supply situation.

The question of military function is a prime consideration, particularly for overseas stations, and the question of available water resources is almost always a second-line consideration in deciding on a station location. Only if there are two or more locations that will fulfill the military requirements do the relative logistics of water resources become an important element in deciding which location to choose. If military functions were completely dominant in all considerations of station location and operation, there would be a water shortage only if there were absolutely no technically feasible method of getting water to the station. On this basis, one could say that there was no shortage of water at any existing station simply because existing stations are all operating to fulfill their mission.

The role of economics in water shortages thus becomes important in deciding what constitutes a water shortage. Hirshleifer, DeHaven, and Milliman,[1] in their analysis of water-supply economics, technology, and policy, contend that water availability in most situations is a function of the users' willingness to pay the required costs, and this has generally proven true of military usage. When necessary, water has been supplied to naval activities at great cost, but this is a rare

circumstance. The implied purpose of this task is to improve the efficiency of shore-station operations and to indicate areas where existing technology can be used to increase efficiency or to discover areas where improved technology may be required to improve overall operations.

If cost efficiency is to be used as a common denominator for defining water shortages, there must be determined a level of reasonable costs and unreasonable costs. Unfortunately, total water costs at naval stations are difficult to assess because of the circumstances of construction and operation of most bases. Large bases with extensive water systems built during World War II may now have great excess capacity that cannot be fairly assessed as a capital cost. Smaller stations may have relatively high labor costs, because the men assigned to the water system cannot be fully utilized, despite efforts to give them collateral duties to improve the overall efficiency. Costs of using military personnel on a part-time or training basis are impossible to account for. Consequently, in deciding a proper cost level for a breaking point to decide when a "shortage" of water was in existence or likely to occur, cost figures from various literature sources and some stations were studied.

Reference 2 shows that municipal total system costs generally are in the range from $0.25 to $0.50 per thousand gallons. Data from the Construction Battalion Center, Port Hueneme, indicates a cost of about $0.25 per thousand gallons (not including any system capital cost charges). Koenig,[3] in his analysis of water costs, shows data indicating the relatively high unit costs that occur in smaller systems, particularly with regard to water transmission and storage. He shows that total costs for a conventional small system frequently may exceed $1.00 per thousand gallons.

To be most meaningful, these costs for a conventional system must be compared to the possible alternatives, which are, generally, demineralization of any available brackish water or desalting seawater. For these methods, there are considerably fewer cost records, but there are many predictions of continually lowering costs for these methods. Lowest actual costs calculated for desalting seawater have been about $1.25 per thousand gallons for an OSW (Office of Saline Water) plant at San Diego, California. Predicted total production costs for large-scale desalting plants have been as low as about $0.25[4] per thousand gallons for a very large system. Small-system costs are likely to remain much higher than this, however.

From the foregoing, it is obvious that even though cost may be the key point in deciding whether or not a water shortage exists or may occur in the future, a cost dividing line would have to be varied somewhat with base size; but for this survey of stations, a figure of $0.50 per thousand gallons "for development of additional supplies" has been used as the dividing line for a water shortage. For most stations, this is a higher cost than would be involved in development or improvement of a conventional system using fresh water from nearby surface or ground water sources, or for obtaining water from an adjacent conventional community water-supply development. On the other hand, this figure is somewhat lower than the total production costs for desalting water that might be expected for most stations.

In more general terms, the definition of water shortage used for this task has been that water shortages will be considered to exist only in situations where adequate supplies cannot be obtained at a reasonable cost by development, improvement, or additions to conventional water systems using fresh water from nearby sources or from conventional community water-supply developments.

FORECASTING REQUIREMENTS

Since the Task Instructions require an estimate of problem areas 15 years in the future, it is necessary to derive certain assumptions as to the likely water requirements for shore stations in 1980. Although it is generally assumed that both the population of the country and the per capita water use will increase considerably in this period, there can be no assurance that naval stations will increase in size proportionally. The obvious complications are the possibilities of a substantial reduction of all military forces because of international agreements or large increases because of increased tensions. Complete mobilization would bring even higher levels of activity, but with lowered per capita requirements on emergency standards. If the general trend of the past decade continues, there will be a continuing small decrease in total naval activity over the next 15 years. Consequently, the requirements of the naval activities are likely to decline slightly, but increases in the percentage of people living in on-board family housing will tend to offset the decline.

There are apparently three likely possibilities for forecasting demands 15 years hence. The first would be that requirements are likely to be static or declining. In gathering and analyzing survey data, this situation has been characterized as a no-change or zero percentage increase in demand. This estimate should be valid as a minimum requirement standard, with the possible exception of substantial decrease — but such a decrease would generally obviate any problem.

A second likely situation is that station size and demands will increase in about the same proportion as the national demand. If they do, the average station demand in 1980 will be about 35% greater than in 1965, and this percentage has been used as a median possibility in the survey. The percentage is based on data from the Senate Select Committee on Water Resources[5] and combines increases in population and per capita consumption.

The third possibility used is that of a substantial increase due to mobilization or near-mobilization requirements. A doubling (100% increase) of water requirements is used to characterize this situation. Such an increase would actually cover about a fourfold increase in active personnel at stations under mobilization, since family housing would not increase under these circumstances. Use of these three likely rates of increase, 0, 35, and 100%, in the survey and analysis should cover all possibilities and yield results that will be widely adaptable.

METHOD OF SURVEY

The general approach to this survey was to first establish the general geographical areas around the world that may have water shortages now or in 1980. With this information, the catalog of naval activities addresses[6] was reviewed to obtain a list of naval stations in these areas. After this list had been prepared, it was reviewed to screen out any stations that were known to have adequate supplies. The remaining list of stations was then subdivided into lists by district or division field engineering offices, and the questionnaire shown as Table I was sent to the appropriate field engineering office to obtain further data on these stations. These offices were also asked to add other stations that might have water-shortage problems, and several additional shortage locations were discovered. Upon receipt of the basic information requested in Table I, several additional requests for data were sent regarding specific station details.

Although the bulk of survey information was obtained through the division engineering offices, certain additional useful data were obtained from the Base Development Branch, the RDT&E Management Branch, the Planning Section, and the Utilities Section of BuDocks.

In addition to the discussion and data derived from the previously noted sections of BuDocks, the OSW was contacted, and the general worldwide water-shortage situation and status of current technological developments as might relate to naval stations were discussed. Information from a number of engineering feasibility studies regarding water supplies at various stations was obtained, and these have shown a close awareness of the problems at the field engineering offices.

EXISTING AND PREDICTED GEOGRAPHICAL SHORTAGE AREAS

After the requirements and methods for the survey were established, basic information on existing and predicted geographical shortage areas was obtained from a number of sources. Because of the vigorous interest in water problems within the United States, a large amount of information on current and projected conditions was found to be available. The most comprehensive and useful were found to be a series of reports developed under the United States Senate Select Committee on National Water Resources. One of these, entitled "Water Supply and Demand: Preliminary Estimates for 1980 and 2000"[5] was particularly useful for the survey. In presenting information on regional demands and shortages, the Senate report defines the quantities required for various basic consumptive and non-consumptive uses and the supplies available from surface and ground sources, but no judgment is made as to the economics of importing water from another region with a surplus.

Table I. Survey Data Sheet

The following naval activities in the ______________ area are located at points that may have a shortage of potable water now or in the next 15 years. On the basis of available data for these activity locations, the following information and estimates are requested.

Activity Location	Cognizant P.W. Office	Current Potable Water Use Ave. gal/mo.	Potable Water Source (wells, surface, catchment)	Activity Popul. Equiv.	Is Potable Supply Adequate	Will supply be adequate in 1980 if activity is increased by:			Can add'l supply be developed at a cost less than about $.50/ 1,000 gal.
						0%	35%	100%	

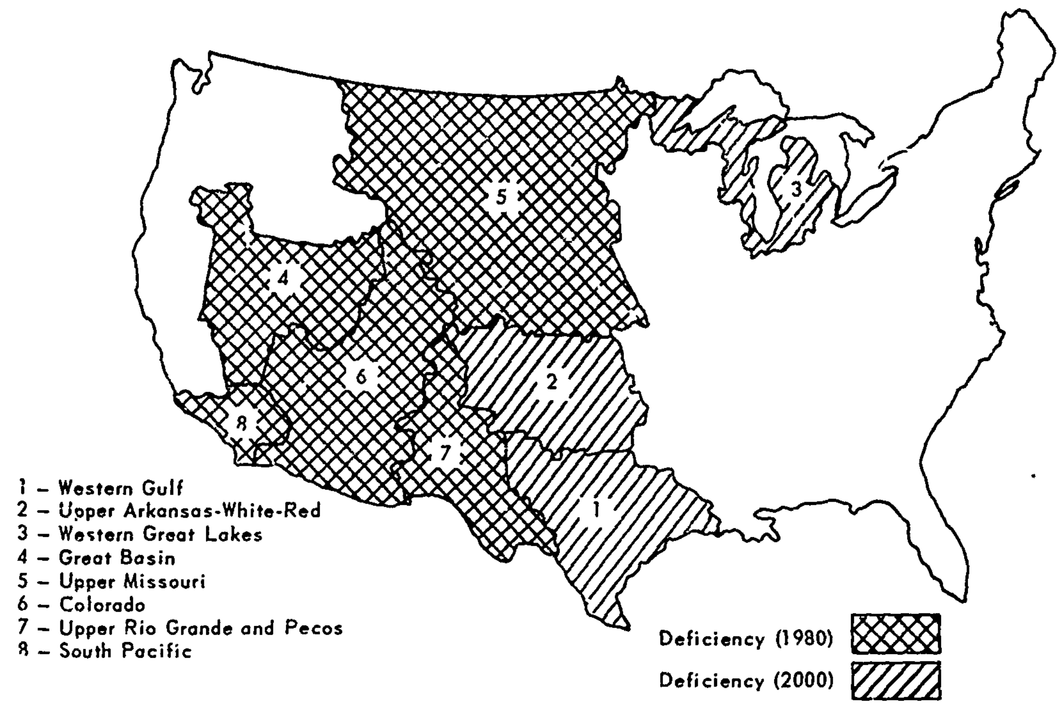
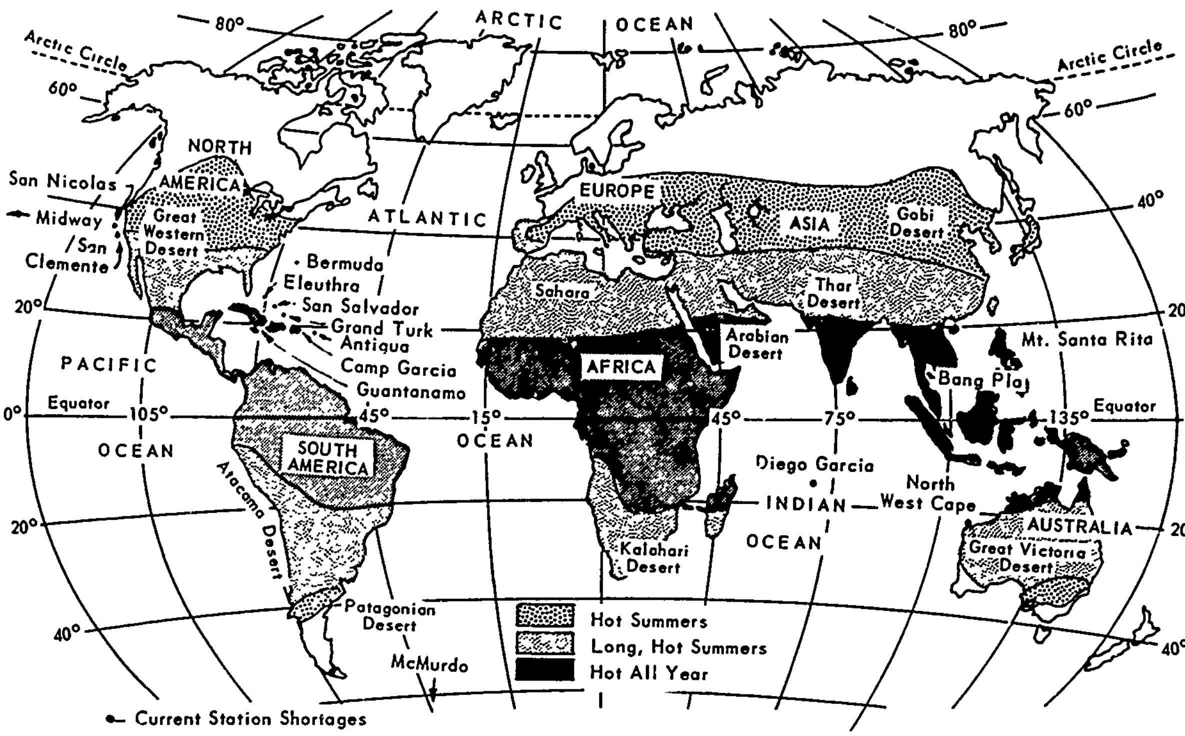


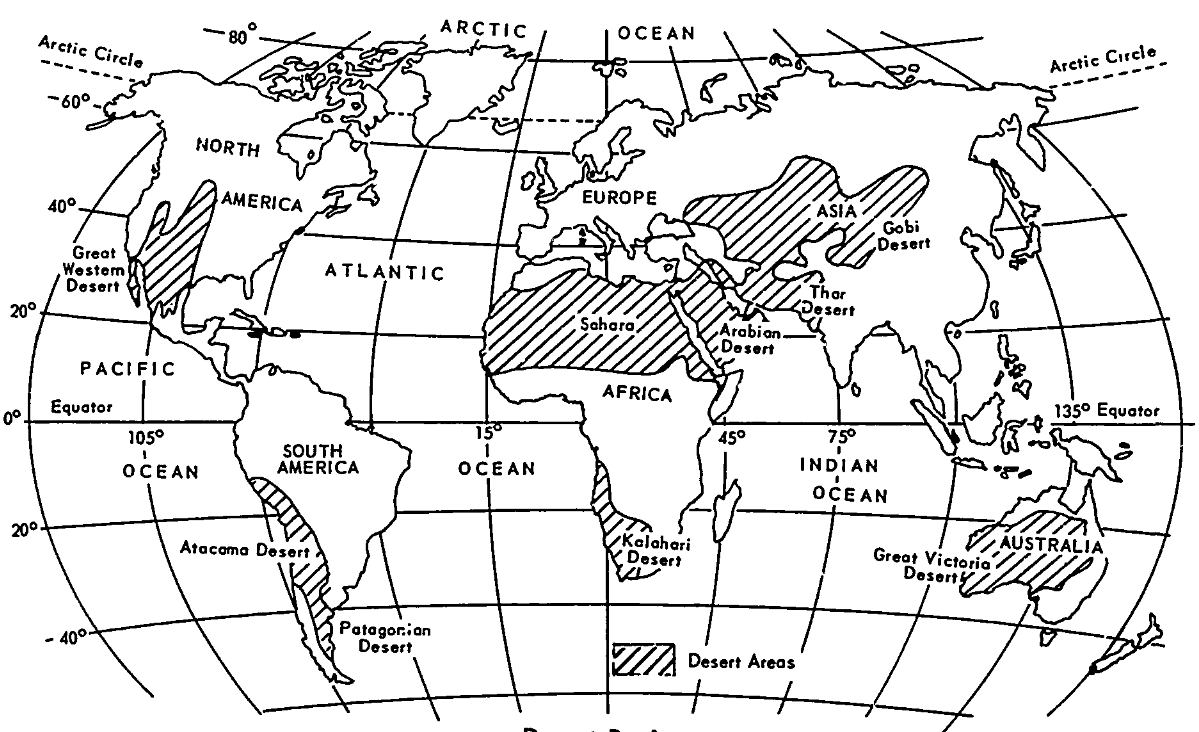
Figure 1. Areas of predicted regional water deficiencies by 1980 and 2000.

The regions of expected shortages of supplies are shown in Figure 1. Several regions have projected deficits by 1980, and additional regions are listed as likely to have deficits by 1980. The most critical region is that titled "South Pacific," which includes a large number of major naval establishments. The region includes southern portions of California and western parts of Arizona. The other regions shown as deficient for 1980 have relatively few naval stations. One region listed as deficient by the year 2000 is in the Texas area, and this also includes significant naval establishments. The Southern California area is actually already importing water, with a state plan underway for additional importations.

Outside the continental United States, there are a number of recognized shortage areas, and several stations have had persistent water problems. However, considerable additional general information on existing or potential shortage areas was found in a recent report of the United Nations.[7] Table II lists a number of nations or regional areas indicated by this report as potential water-problem areas. Figure 2 shows worldwide high-temperature and desert regions and has been derived from published information on climatic regions or from data on locations that are known shortage areas. Locations of naval stations in these regions are also indicated.



High-Temperature Regions



Desert Regions

Figure 2. Adverse climatic areas.

Table II. Problem Areas in Other Countries[7]

Africa	Asia	Europe	Caribbean-South America
Canary Islands	Bahrain	Guernsey	Argentina
Ethiopia	India	Cyprus	Bahamas
French Somaliland	Indonesia	Greece	Barbados
Kenya	Iran	Maltese Islands	Bermuda
Libya	Israel	Spain	Brazil
Madagascar	Jordan		Chile
Mali	Kuwait		Ecuador
Mauritania	Pakistan		Mexico
Somalia	Qator		Netherlands Antilles
South Africa	Saudi Arabia		Peru
South-West Africa	Turkey		Venezuela
Spanish Sahara			Virgin Islands (U.K.)
Sudan			Virgin Islands (U.S.)
Tunisia			
United Arab Republic			

GENERAL RESULTS OF SURVEY

As a result of a comparison of the naval addresses and the geographical shortage areas, a list was developed of about 80 station locations that might have an existing or potential potable-water shortage under the conditions assumed or projected to 1980. The questionnaire shown as Table I was then sent to the Southeast, Southwest, European, Pacific, Caribbean, and Western Divisions to obtain the required information. Follow-up requests were made to some individual stations and field offices for specific additional information.

As a result of the information furnished on these questionnaires and from other Yards and Docks offices, the 16 stations listed in Table III are judged to have a potable-water-shortage problem under the conditions assumed or projected for this survey. All but one of these problems are already existing and are not because of projected demands of 35 or 100%. One shortage, at Guardamar, Spain, would occur only at a 100% increase in demand. The shortages are all of an "economic" nature, and additional supplies can be obtained by expenditure of funds of significant but not overwhelming amount. One location, Antigua, was reported to be currently short of water because of an extended drought, but it, and all others listed, are apparently operating to perform their assigned functions.

Three locations have the problem of having brackish water available, but no ready source of fresh water or seawater. Eight of the problem areas are small islands, four are coastal locations that are unfavorable for conventional water supplies, and two are remote sites without suitable surface or ground water.

A total of about 60 million gallons per month is being distilled, with the majority of this at Guantanamo. Stations using catchment are also classified as having water problems, and this method has the next greatest production rate covered by the survey, with a total of between 7 and 8 million gallons per month being used, mostly at Midway. Tanker supplies total about 1.5 million gallons per month. Other water-production methods in problem areas include electrodialytic demineralizing in use or under consideration at three locations, and snow melting in the Antarctic. An aggregate production of about 68 million gallons per month is involved in all nonconventional methods.

The survey of stations also indicated that there are problem areas within the continental United States where cost levels are approaching $0.50 per thousand gallons or that have a likelihood of problems beyond 1980, although no continental station actually indicated a shortage problem within the shortage definition used. Because of the potential problems, the situation in Southern California, the Gulf Coast, and Key West is covered along with further discussion of the existing problem areas in later sections of this report.

Table III. Shortage Locations

Location	Present or Projected Potable Water Use (gal/mo.)	Water Supply	Approximate Population	Nature of Shortage
Guantanamo	52,000,000	Distilled seawater	5,000	No fresh water on station
Midway Island	4,500,000 (plus 10,000,000 non-potable)	Catchment Brackish wells Seawater	3,000	Catchment storage costs high
Northwest Cape	1,800,000	Demineralized water from brackish wells	1,000	Electrodialysis costs will be about $1.00/1,000 gal
McMurdo	1,000,000 (est.)	Melted snow Distilled seawater	500 (variable)	All methods expensive
San Clemente Island	2,500,000	Surface and tanker	725	Scarce local water
San Nicolas Island	1,800,000 750,000	Tanker Surface	500	Scarce local water
Bang Pla	300,000	Brackish well water to be demineralized	75	Electrodialysis probably necessary
Diego Garcia Island	not established	Distilled seawater (projected)	700	Scarce local water
Antigua	457,000	Catchment wells	110	Present sources inadequate. Distillation most likely supplement
Eleuthra	345,000	Catchment	110	Catchment inadequate for expansion of facilities
San Salvador	272,000	Catchment Distillation	110	Catchment supplemented by VC distillation
Grand Turk	211,000	Distillation	100	Catchment supplemented by VC distillation
Mt. Santa Rita	180,000	Electrodialysis of brackish well water	-	Brackish water at site
Guardamar	225,000	Catchment	25	Present supplies adequate; cost of doubling supply estimated to exceed $0.50/1,000 gal
Camp Garcia	6,000,000	Wells	3,100	Wells inadequate; further ground sources being investigated
Bermuda	2,000,000	Catchment	1,000	Potable supply cannot be increased at reasonable cost

San Nicolas and San Clemente Islands

These two islands lie a short distance off the California coast and currently use local water supplies, supplemented by water shipped from Long Beach. They serve for various training and test activities in conjunction with commands located on the mainland. Both have already been the subject of engineering studies to determine the most feasible methods of water supply, and some of the information developed in connection with these studies is summarized and discussed in the next paragraphs.

San Nicolas Island water supply and storage problems were the subject of a preliminary engineering study[8] by a consulting engineering firm under a contract in 1961. Population on the island fluctuates somewhat, but averages around 500. Daily average consumption in August 1964 was about 85,000 gpd with 60,000 gpd being from water shipped in from Long Beach and the remainder from surface sources on the island. The indigenous water is of poor quality.

The contract engineering study recommended a 30,000-gpd flash-distillation system, with water tankers as the principal alternative. Other alternatives considered included runway catchment and storage, salt water flushing and fire system, and surface impoundment by a dam.

Total cost of the desalted water was predicted as about $6.00 per thousand gallons including amortization of $420,000 capital costs over 15 years. However, this figure includes certain distribution costs, and a revised figure, eliminating distribution, is calculated in Table IV as $3.68 per thousand gallons.

The current cost of shipped water is estimated at about $7.00 per thousand gallons (see Table V), not including amortization of any shore facilities. The contract noted previously included about $30,000 per year for amortization of shore facilities, and this, added to the transportation and handling included above, would make the cost of shipped water about $8.00 per thousand gallons at the current rate of shipment, and this still does not include distribution costs on the island.

The 30,000-gpd distillation proposed by the engineering study would obviously be inadequate for the current island demands, but a 60,000 to 75,000-gpd plant would undoubtedly be more economical than the $3.68 per thousand gallons estimated for a 30,000-gpd plant. The big question regarding this type of plant would be whether or not a sufficient percentage of the capacity would be used over a 15-year period to make this estimate valid. The current usage of shipped water accepts higher operating costs in preference to the risk of a high capital investment that may not be exploited.

San Clemente water requirements have been estimated at a minimum of 85,000 gpd by cognizant authorities, with an additional 50,000 gpd desirable for irrigation of ground cover to control wind erosion of soil near essential facilities. About 50,000 gpd are now being shipped to supplement local supplies.

A population of about 725 persons is projected for the island. A salt water system serves for fire protection.

Because of the apparent possibility of economies to be gained by desalting, the OSW was requested to make a survey of desalting methods suitable to the island that also might be funded, at least partially, by OSW funds. This study concluded that use of a freezing process would be most in line with OSW research and demonstration program. This and other methods are apparently still under consideration.

The situation at San Clemente is complicated by substantial annual variations in population and considerable doubt as to the probable future demand. Consequently, methods that require substantial capital expenditures cannot be amortized over long periods of time to yield a reasonable unit production cost. The cost estimates previously cited for San Nicolas Island are generally applicable to San Clemente Island.

McMurdo, Antarctica

The polar regions have probably the most serious problems of water shortage. The problem of obtaining water, along with the difficulty of distribution and sewage collection, generally limits polar camps to fairly primitive sanitation systems, with corresponding detrimental effects on camp efficiency.

The situation typified by the McMurdo facility in the Antarctic is the worst problem. Limited quantities of snow are available, access to seawater is difficult, and fuel is expensive. Water usage in such camps is usually no more than about 25 gallons per man per day. Assuming a fuel cost of about $1.00 per gallon, because of the large transportation and storage expenses, it can be expected that potable-water-production costs will be in the range of $50 to $150 per thousand gallons[9] for snow melting or distillation. Distribution systems will be extremely expensive and are a greater limiting factor than production costs.

Midway

The water supply system at Midway uses three sources and has three separate distribution systems. The potable supply is from rain catchment on runways. The catchment water is used in drinking fountains, galleys, the laundry, and for other potable uses. Brackish well water is distributed in a second system to showers and wash basins, and seawater is pumped in a third system for flushing. When excess catchment water is available, it is pumped into the brackish system to minimize draft on the wells. A maximum of 14,000,000 gallons (including treatment basins) of catchment storage is provided. Monthly average pumpage is 4,900,000 gallons of catchment water, 6,000,000 gallons of brackish water, and approximately 4,000,000 gallons of seawater.

The cost of catchment storage for Midway is readily estimated. Based on BuDocks estimating information,[10] the unit cost of large steel tanks at Midway can be calculated as $0.117 per gallon capacity. At this rate, the 12 million gallons of special catchment storage cost $1,400,000. On a 20-year life, with interest at 3% and with 2% per year for maintenance, the annual total cost for storage is about $120,000. Since an average supply of 60,000,000 gallons per year results from this storage, the cost per thousand gallons is $2.00. The actual total cost of production is somewhat higher than just the storage cost and would include cost for runway drainage grading, collection pumping, sedimentation, and pH correction, so the total production cost of catchment water would be close to $3.00 per thousand gallons.

In addition to the high cost of potable water, Midway could also be classed a shortage area because of the possibility of a long dry season causing a complete exhaustion of potable supplies. Existing supplies are not considered adequate for a 100% expansion of needs. If a major revamping or expansion of facilities on Midway were made to consolidate power systems and improve water supplies, it is likely that a flash-distillation plant could be incorporated into the power plant to provide a significant quantity of potable water at a reasonable price to supplement the catchment system.

Northwest Cape (Australia) and Bang Pla (Thailand)

These two facilities are currently being constructed under the Pacific Division and have a similar problem of having only limited supplies of brackish water nearby, although the Northwest Cape facility has access to seawater at a short distance.

Total solids in the brackish water at Northwest Cape approach 2,000 ppm and are between 2 000 ppm and 4,000 ppm at Bang Pla. Electrodialysis has been selected as the method for obtaining potable supplies at Northwest Cape, with the reclaimed sewage effluent to be used for irrigation. Final selection of a method for Bang Pla has not been made, but electrodialysis is the likely choice.

Potable-water-production cost at Northwest Cape will cost about $1.00 per thousand gallons on the basis of data received from the Pacific Division.

Guantanamo

The maximum capacity of the flash-distillation plant at Guantanamo will be 2.25 mgd and will consist of three 0.75-mgd units. One of the three units is the OSW experimental plant formerly located at San Diego, and the others are new but similar units. Coinciding with the installation of these units, a new steam generating and power plant has been built. Cost of the water produced will probably fall in the range of $1.25 — $1.50 per thousand gallons.

Although the shortage of water and the need for distillation have been caused by international problems, the information that will result from the installation and operation of the plant will be extremely valuable in determining the feasibility of future dual-purpose plants of this type for many of the problem areas listed in this report.

Vieques Island (Camp Garcia)

Camp Garcia on Vieques Island is using 6,000,000 gallons per month from wells that are indicated to be inadequate. Further explorations of ground-water possibilities is underway and may resolve the problem with a conventional supply.

Since the island is relatively close to Puerto Rico, the ultimate solution in the event suitable ground water is absent will depend on the relative economics of transporting water versus demineralization or desalting.

Small Islands

Information received indicates that there are six island stations with definite shortage problems. Facilities at four of these, Antigua, Grand Turk, San Salvador, and Eluethra, are under the Caribbean Division, and one is a planned station on Diego Garcia Island in the Indian Ocean. The monthly water requirements are in the range of 200,000 to 500,000 gallons at Antigua, Grand Turk, San Salvador and Eluethra.

Water requirements at Diego Garcia may be as high as 2,000,000 gallons per month, and this facility would seem to be a likely location for a dual-purpose power-waterplant in one of the several possible configurations that such a plant can take.

Antigua has no distillation equipment to supplement catchment water and is stated to be currently extremely short of water. Distillation of supplementary water was stated by the Caribbean Division to be necessary to assure fulfilling Navy requirements.

Other Distant Areas

The survey indicated two small facilities with water shortage problems. They are Guardamar in Spain and Mt. Santa Rita in the Philippines. The Guardamar facility uses catchment water. Current supplies are adequate, but data from the European-Mideast Division indicate that a 100% expansion cannot be fulfilled without exceeding the cost of $0.50 per thousand gallons.

The Mt. Santa Rita facility utilizes demineralization of brackish water by electrodialysis. Experience with this method has been satisfactory there.

Southern California Bases

Southern California was previously shown as one of the sections of the United States most likely to have a general shortage of water by about 1980. Since there are a number of large stations in this area, it has been the subject of a review of projected available quantities and costs as part of the survey, even though no station is expecting a water-shortage problem by 1980.

The majority of large stations in Southern California are already directly or indirectly dependent on water imported by the Metropolitan Water District or other civil agencies from the Colorado River or from Northern California. The California Water Plan to transport water from Northern to Southern California is intended to supplement existing local and imported supplies to insure adequate supplies for both agricultural and municipal (including industrial) use for the foreseeable future.

Figure 3 shows the probable locations of the California Water Plan[11,12] aqueducts and the areas that probably will be served by these facilities. On this figure, the locations of major naval activities discussed in this report are shown. Several stages of this plan are already under construction.

The stations in Southern California that do not use water from civil water authorities generally depend on wells. Major establishments using wells for all or most of their water include the bases at Port Hueneme and Point Mugu, the Ordnance Test Station at China Lake, the Marine Base at Twenty-nine Palms, and Camp Pendleton. Discussions of these supplies with personnel at the Southwest Division indicates that the wells at Camp Pendleton would not be adequate for a 100% expansion of that facility. Areas for surface impoundment may be available and adequate, or supplementary water could be obtained through use of imported water from civil water districts. None of these sources is likely to exceed the cost boundary of $0.50 per thousand gallons, but probably will be close to that.

The capacity of the underground sources serving the Port Hueneme — Point Mugu area is somewhat in doubt; and the Southwest Division is planning further studies of this problem, since this water would be relatively cheap, even after treatment to improve quality. If this supply is shown to be inadequate for projected demands, these stations would also be obliged to obtain imported water through civil water authorities.

The underground supplies for Twenty-nine Palms and China Lake are reported to be adequate for all projected demands.

Western Gulf Coast and East Coast

These regions are experiencing rapid industrial and population growth and are expected to continue to do so.

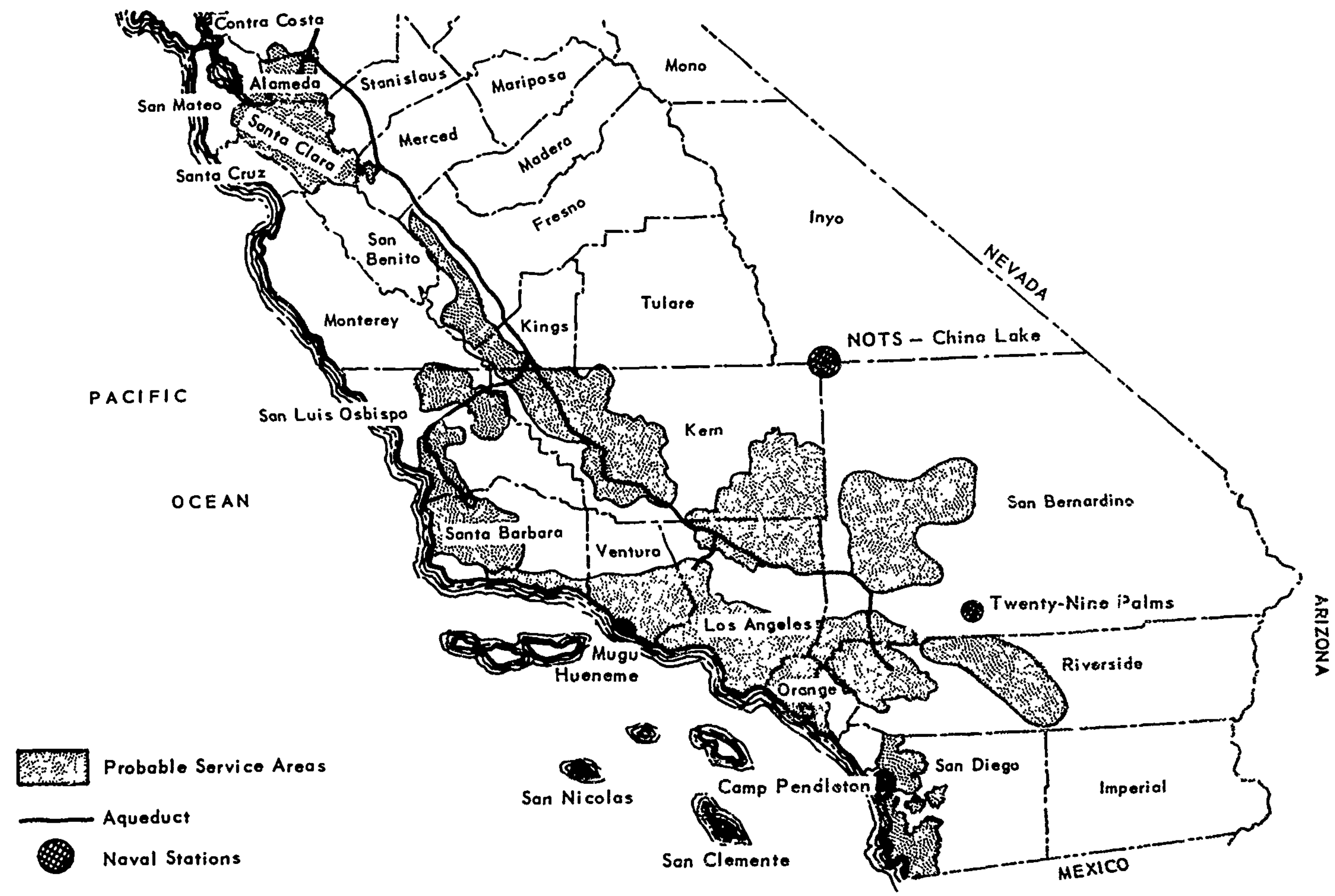


Figure 3. California Aqueduct and probable service areas.

The Senate Select Committee report[5] indicates a possible overall deficiency in the Gulf Coast area by the year 2000, but a regional water survey[14] indicates that the area of immediate concern is limited to inland regions and to a southerly portion of the coast near Mexico. One electrodialysis plant for municipal use is being planned in the latter area. The East Coast regions of the United States are amply supplied with water on an overall basis, but intense population and industrial concentrations tend to create situations of temporary local shortage. Tentative plans have been announced for a desalting plant at a municipality on Long Island, the area of most intense problems. As in Southern California, the water problems of stations in the Gulf and Eastern areas are likely to be resolved through agreements with civil water authorities.

Key West

The complex of naval activities on the Florida Keys is served by wells on the mainland, with a 130-mile pipeline to Key West. The line also serves other users and is now approximately at capacity. Methods of supplementing the supply for the other users are now under study by the Florida Keys Aqueduct Commission, a civil water authority. Any expansion of Navy requirements could be made only at the expense of civil requirements. Available alternatives include expanded pipeline facilities and desalting seawater. Demineralizing brackish water might also be considered, since there is some brackish water available.[14] Initial studies were made by an Aqueduct Commission contractor on the feasibility of a combination nuclear power plant and desalting facility. This proved to have a high capital cost and a fossil fuel power — desalting system is being considered.

Electrodialytic demineralization of brackish well water could conceivably provide a supplementary supply in this area at a lower cost than desalting. However, the situation here is sufficiently complex to demand a detailed economic study whenever a decision to increase the overall capacity of the Navy supply is made.

WATER-SUPPLY METHODS FOR SHORTAGE LOCATIONS

Results of this survey have shown a substantial number of stations that currently do not have conventional potable water supplies at a reasonable cost. The various alternatives in use generally seem to have been carefully selected on the basis of engineering surveys and estimates made by the cognizant division offices or by engineering consultants. Means of reducing costs and selection of the most advantageous methods for current and future problems can only be made by detailed study of the specific sites and conditions at the time the need is defined, but the literature search and review of general approaches to the water problem made in connection with this task have revealed interesting and useful information on several aspects of the water problem. Methods in use or likely to be used are described, with indications of costs and limitations, in the following sections.

Non-Potable Supplements; Capabilities and Costs

The extent to which demand on the potable system is minimized by use of seawater and other non-potable supplements is variable. Seawater serves about 30% of the total water demands at Midway, but a proposed system at San Nicolas Island is estimated to offer only a 10% supplement. A separate seawater fire system has little effect on daily consumption, but it can minimize potable reserve storage.

The approximate water cost for supplemental seawater at San Nicolas is shown as $14 per thousand gallons in Table IV. Table V gives an estimate of the cost of shipping water to San Clemente and San Nicolas islands. Another estimate based on costs for supplying seawater for flushing to an island station is shown as Table VI. This estimate indicates a cost of $2.90 per thousand gallons, most of which is caused by assuming that $0.50 to $1.00 per square foot will be added to the cost of all structures to provide the separate building connections and plumbing for salt water. An estimate of a unit cost of $0.98 per thousand gallons is shown in Table VII for a 200,000-gpd system.

The portion of total water demand that can be met with reclaimed sewage or other water is also highly variable. Preliminary data on the Northwest Cape facility indicate the basic potable supply will be 60,000 gpd and that 45,000 gpd of sewage-treatment-plant effluent will be used for irrigation. Data from San Clemente Island indicate a need for 50,000 gpd of irrigation water in comparison to a potable consumption of 85,000 gpd. The cost of sewage treatment will usually be lower than almost any water-production method in shortage areas, and the main limitation on use is the cost of distribution. This factor will frequently limit feasible usage to special areas. Heishliefer, et al,[1] estimate that treated sewage could cost as little as $0.05 per thousand gallons from large-scale plants. Average cost of treatment runs $0.10 to $0.20 per thousand gallons.[2]

Non-potable supplements are most commonly used where catchment or desalting of sea or brackish waters is used for the potable supply. A possible major use of brackish water is for cooling purposes, and the adaptability of brackish waters for cooling purposes may be enhanced simply by softening. This procedure may be of considerable value at communications stations with cooling-tower-water demands that can be met with little additional distribution piping. These arrangements are best worked out during initial station-design planning.

Desalting

Although use of non-potable waters to supplement a scant supply of potable water will alleviate some shortage problems, most of the shortage situations listed in the survey results have involved the necessity of desalting brackish or seawater.

The three principal methods currently commercially available for desalting are electrodialysis, multistage flash distillation and vapor-compression distillation. Selection of method is considerably dependent on the type and quantity of mineralized water available, and on the duration and nature of the use.

Table IV. Estimated Costs for Salt-Water System or Flash-Distillation System for San Nicolas Island, California

Flash Distillation System (30,000 gpd; 10,500,000 gpy)

Installation:

Complete intake system	$ 34,400
1,500 ft of 8" pipe and appurt nances	13,900
Distillation plant complete	171,100
Outside storage and other appurtenances	24,600
Total (not including any distribution, fire mains, or storage)	$244,000

Annual Costs:

Depreciation, 15 years	$ 16,200
Operation and maintenance	10,000
Fuel	8,000
Interest, 4%	4,880
Total	$ 39,080
Per 1,000 gallons	$ 3.68

Salt Water System for Fire & Flushing (6,000 gpd; 2,200,000 gpy)

Installation:

Intake complete	$ 40,000
Booster pumps and building	15,000
11,900 ft of pipe to fire storage	114,000
Salt-water storage tank (400,000 gal)	55,000
Plumbing conversion in selected bldgs.	15,000
Total	$239,000

Annual Costs:

Amortization	$15,900
Interest, 4%	4,800
Operation and Maintenance	10,000
Total	$30,700
Per 1,000 gallons	$ 14.00

Table V. Estimated Cost of Shipping Water to San Clemente - San Nicolas Islands[1]

Cost Summary: 18,000,000 gpy

Interest on vessel cost	$ 11,985
Amortization, 50 years	13,315
Crews, maintenance, and fuel	103,500
Water purchase at mainland	3,600
Total	$133,000
Per 1,000 gal	$ 7.39

[1] Based on estimate by A. Bleiweis, Code 41.320, BuDocks.

Table VI. Cost Estimate for Salt-Water Flush System for a 750-Person Station (500 Men, 250 Dependents) on a Remote Island

Capital Costs: 30,000 gpd; 10,500,000 gpy

Intake and pump system	$ 50,000
Distribution mains (5,000 ft)	34,000
Building connections and extra plumbing	
Barracks — 60,000 sq ft at $0.50/sq ft	30,000
BOQ, etc. — 30,000 sq ft at $0.75/sq ft	22,500
Family Hsg. — 90,000 sq ft at $1.00/sq ft	90,000
Adm. & Work Areas — 150,000 sq ft at $0.50/sq ft	75,000
Total	$301,500

Annual Costs:

Amortization, 20 years	$15,100
Interest, 4%	6,000
Operation and maintenance	3,200
Added plumbing maintenance	9,000
Total	$33,300
Per 1,000 gal	$ 2.90

Table VII. Cost Estimate for Salt-Water Flush System for a 3,000-Person Station (2,200 Men, 800 Dependents) on a Remote Island

Capital Costs: 200,000 gpd; 70,000,000 gpy	
Intake and pump system	$ 75,000
Distribution mains, 9,000 ft	58,000
Building connections and plumbing	
Barracks — 200,000 sq ft at $0.50/sq ft	100,000
BOQ, etc. — 100,000 sq ft at $0.75/sq ft	75,000
Family Hsg. — 240,000 sq ft at $1.00/sq ft	240,000
Adm. & Work Areas — 200,000 sq ft at	
	100,000
Total	$648,000
Annual Costs:	
Amortization, 20 years	$32,400
Interest, 4%	12,900
Operation and maintenance	10,500
Added bldg. plumbing maintenance	13,000
Total	$68,800
Per 1,000 gal	$ 0.98

Electrodialysis. Electrodialysis is best suited to situations where limited supplies of water containing less than about 5,000 ppm total dissolved solids are available. This method needs about 1.6 gallons of brackish water input to produce 1 gallon of potable water. Demineralization is possible to the point where chloride and sulfate concentrations are reduced to about 250 ppm each and total dissolved solids are reduced to 500 to 1,000 ppm.

Electrodialysis is now a well-developed technique for demineralizing brackish waters for industrial and domestic purposes, but the process is technically feasible even for seawater. Preconditioning of the feedwater to prevent scale and slime deposits in the units may be necessary.

A recent installation of this type at Buckeye, Arizona, is reported[15] to be producing water at a cost of $0.63 per thousand gallons, but future costs are likely to be lower as the load factor improves. Table VIII shows the breakdown of this cost. Plant capacity is 650,000 gpd. Labor costs are minimized by having a versatile auto mechanic run the plant on a part-time basis while also maintaining the town's vehicles. Initial plant cost was approximately $300,000 including a storage tank and building to house the unit.

A similar but smaller plant at Coalinga, California,[16] produces 25,000 gpd at cost of about $1.50 per thousand gallons.

Multistage Flash Distillation. Flash distillation requires large quantities of water input (12 to 20 times potable output) and is best suited for operations in conjunction with an electric-power-generating system from which it can obtain primary or waste heat at a lower cost than when a steam generator serving only the still is used. However, the latter method is also quite feasible. Location near the sea and at or near sea level is also desirable to minimize pumping costs.

When operated in conjunction with a diesel engine, waste heat can be used from the engine-jacket water and the exhaust. Waste heat is best utilized if the engine is operated with a boiling-condensing cooling system. This cooling system provides the waste heat at a higher and steadier temperature and allows use of fewer stages in the flash system. Extraction of waste heat from a conventional cooling system is feasible, but somewhat less desirable overall. In the case of communication stations with relatively large generator capacity, the available waste heat from a conventional cooling system may be more than adequate.

Initial cost for a 30,000-gpd flash-type plant will be in the range of $2 to $4 per gpd capacity, depending on the number of stages, and does not include engine changes or intake and storage facilities. Electricity would be about 12 kwh per thousand gallons for pumps, etc., on the evaporator. If no waste heat is available, about 1 pound of steam is required for every 5 to 10 pounds of product water, depending on the number of stages. A large flash-distillation plant installed at St. Thomas in the Virgin Islands as part of a power station is reported[7] to be producing 250,000 gpd at $2.54 per thousand gallons. Initial cost for the water-supply section is set at $1,100,000. Fuel cost is assessed at $0.57 per thousand gallons. As noted previously, a 1-mgd plant at San Diego is estimated to have produced water for $1.25 per thousand gallons.

Table VIII. Electrodialysis Costs at Buckeye, Arizona

Cost Breakdown: Production of 80,000,000 gpy in a 230,000,000-gpy plant

Item	Cost (Cents/1,000 gal)
Electricity (12 kwh/1,000 gal)	12.9
Acid	0.6
Filters (prefiltration)	3.2
Membrane replacement	7.5
Other parts	5.0
Labor	6.9
Miscellaneous	1.4
Bond amort. & interest	25.5
Total	63.0

Table IX. Vapor-Compression Distillation Costs at Kindley AFB (Bermuda)

Cost Breakdown: Production of 42,000,000 gpy in a 200,000-gpd plant (Four 50,000-gpd units)

Item	Annual Cost
Maintenance (including labor)	$ 60,000
Operation labor	57,000
Power	4,500
Fuel	20,000
Acid	18,000
Total	$159,500
Per 1,000 gal	$ 3.70

Vapor-Compression Distillation. Vapor-compression distillation requires much less raw water than flash distillation and produces one gallon of potable water for every 1.5 to 2 gallons of water used. Units are best suited to short-term requirements where no waste heat is available.

A large plant of this type is in use at Kindley Air Force Base in Bermuda. This base also uses a catchment-water system and a seawater non-potable system. A recently published summary of data[17] is shown as Table IX. Not including capital expenses, the water-production cost is $3.62 per thousand gallons. If depreciation and amortization were added, the cost would be about $5.00 per thousand gallons. Acid for cleaning and power represent only about $1.00 per thousand gallons.

The largest currently available vapor-compression stills are about 10,000 gpd in capacity, but larger units can be constructed if required. Basic cost of this type unit is in the range of $3 to $4 per gpd capacity. Intake pumps and lines, housing, and production storage are additional.

Catchment

Rain catchment forms the basic supply for many island communities, military and civilian. The "production" cost of catchment water is largely a function of the storage capacity and catchment-area paving required, and the maximum expected length of a dry spell usually determines these requirements. Paving may cost little or nothing if runway and roof surfaces are properly designed at the time of their installation, but storage expense is always involved. Table X shows the effect of storage expense on water costs in terms of the number of times of annual turnover in the tanks. This table also includes an estimate of water cost based on a 4-month maximum dry spell and considerable paving. Costs rise sharply when average annual turnover in storage is only 2 or 3 times. The catchment system always has some uncertainty of capacity because of the difficulty of predicting rainfall-yield patterns, and water demand is greatest when yield is lowest.

DISCUSSION OF SHORTAGE PROBLEMS

Cost figures reported from various sources are plotted on Figure 4. Except for the point indicating Midway catchment-storage costs, the values indicate total production costs per thousand gallons, with production interpreted to include all costs approximately to the point where the water is ready to enter distribution pumps. Costs also include appropriate depreciation and capital interests, so they are on a comparable basis. The relationship of conventional local production to electrodialysis production from brackish water and flash-distillation production from seawater is readily apparent, as is a substantial increase in unit costs when production is small.

Table X. Catchment Cost Factors

Estimate of Water Costs for Catchment System:

Yielding 8,500 gpd (3,000,000 gpy)
Based on 4-month dry spell and 10-inch runoff

Capital Costs:

Paving — 50,000 sq ft at $0.30/sq ft	$150,000
Storage — 1,000,000 gal at $0.10/gal	100,000
Appurtenances	10,000
Total	$260,000

Annual Costs:

Amortization, 20 years	$ 13,000
Interest, 4%	5,200
Maintenance	5,000
Total	$ 23,200
Per 1,000 gal	$ 7.75

Effect of Annual Turnover on Storage Cost:

No. of Average Annual Turnovers	Storage Cost ($/1,000 gal)	
	If storage Const. Cost is $0.10/gal	If Storage Const. Cost is $0.16/gal
1	10.00	16.00
2	5.00	8.00
3	3.30	5.30
4	2.50	4.00
5	2.00	3.30
10	1.00	1.80

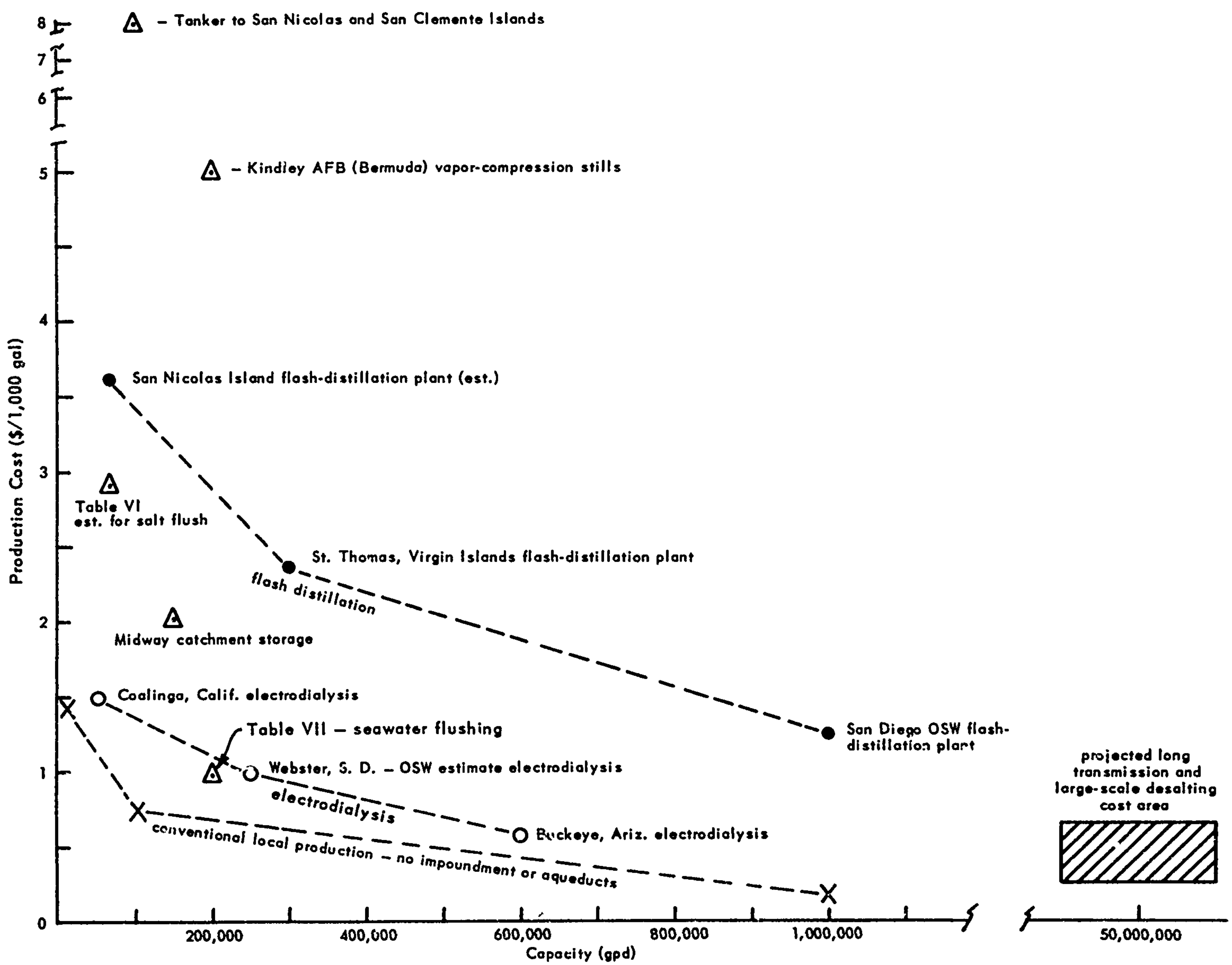


Figure 4. Production costs for methods used in water-short areas.

The Midway catchment-storage cost estimate is lower than current flash-distillation costs, but catchment costs can easily become greater than distillation costs if extensive paving is required or if average turnover in storage is only about 3 times a year as compared to 5 times a year at Midway.

The general pattern of these points confirms the preferences used in selecting supplies for the overseas facilities. Use of local supplies is an obvious first choice, but if this is not available, the local circumstances must be carefully weighed to determine which method or combination of methods can be used to provide a reliable supply at a minimum cost.

Within the United States, the current state of development in supplying water to deficient regions is one of competition between large-scale distillation plants (probably using nuclear reactors as a heat and power source) and the piping of natural supplies over long distances. Resolution of this competition is particularly pertinent to Southern California stations where naval stations frequently buy water through civil authorities when the more economical local sources become inadequate. The main question concerning these stations is the possibility of developing desalting methods that might allow favorably located stations to desalt water on-station to supplement the local supplies at a lower cost than purchased water. Because of the relatively high mineral concentration in many wells in the area, desalted water would have a secondary benefit of improving the overall quality when mixed with local supplies.

The California Water Plan presumably will make an adequate supply available to the stations in the general area. Preliminary estimates indicate a cost of about $0.20 per thousand gallons at the aqueduct in the Los Angeles area and over $0.30 per thousand gallons at the aqueduct in the San Diego area, although critics of the plan frequently cite alternative cost computations that indicate a much higher cost. Predicted costs for larger scale desalting are also controversial, but are frequently in the range of $0.25 to $0.50 per thousand gallons for 50- to 500-mgd plants.

The Metropolitan Water District, the largest civil water authority in the region, is currently planning to use both California Water Plan imported water and desalted water produced in conjunction with power stations in the future, although their reported predicted cost[4] of desalting is somewhat higher, even in an extremely large plant. Since desalting is considerably more expensive in small-scale plants, the advantages to naval stations in Southern California are likely to remain with a program of procuring necessary supplemental water through civil authorities which are importing or desalting very large amounts of water. Even so, it is obvious that stations using water from civil authorities may find their water costs increasing greatly. Since well water now costs some stations only about $0.05 per thousand gallons or less, a switch to imported water or desalted water from a civil authority might well mean a fivefold increase in water cost. With about 500 mgd of water involved for Navy use in Southern California, an increase of only $0.10 per thousand gallons in average cost could result in an increase in Navy utilities costs of $1,800,000 annually.

Consequently, it would appear desirable for definite steps to be taken to conserve existing local supplies in this area. Such steps might include action to preserve or establish legal rights to ground or surface waters on or under the stations, agreements with local civil authorities on existing off-station reservoirs, metering of station distribution systems, internal cost accounting that would charge higher costs to large users, and leakage surveys.

WATER-QUALITY PROBLEMS

After the results of the water-shortage survey were received, a questionnaire covering potable-water-quality problems was sent to all BuDocks Division offices. Information on quality problems not responding to conventional treatment was especially requested, and boiler and heating systems were not expected to be covered.

Of the 14 questionnaires sent out, 11 answers were received. Information received is tabulated in Table XI.

Table XI. Summary of Quality Problems

Division	Problems Noted
Eastern	Scaling and corrosion at U. S. Naval Hospital, St. Albans, N. Y.
Chesapeake	Soluble iron at U. S. Naval Academy, Annapolis, Md.
Atlantic	Corrosive water at Bainbridge, Md.
Southeast	Scaling and corrosion are a general problem
Gulf	High dissolved solids and excess chloride and sulfate at one station; corrosive water at one station
Western	Scaling, corrosion and high TDS at Lemoore, Calif; arsenic at Fallon, Nev.
Northwest	Scaling and corrosive water each at one station
European	Excess mineral concentrations at two stations where water is not under Navy cognizance
Pacific	Excessive TDS, hardness and scaling at Barbers Point, Hawaii; corrosive colored water at Midway Island

Results of the questionnaire indicate that the corrosiveness of the potable water supply poses the most frequent quality or treatment problem. This was noted in seven out of the 11 answers received. Other problems recorded in order of frequency mentioned are scaling water (5 times), and excessive total dissolved solids and hardness (4 times). Water-quality problems intemized at least once on the data sheets compiled are as follows: taste and odor; color; and presence of arsenic, chlorides, fluorine, nitrates, soluble iron, and sulfates.

Bacteriological, biological, and turbidity problems were conspicuous by their complete absence from any of the reports received.

Although no reply was received from the Southwest Division, the problems of scaling, corrosion, excessive hardness and high total dissolved solids are known to occur in this division also.

The prevalence of scale, corrosion, and mineral-concentration problems reflects a lack of accurate analytical techniques to show whether or not a given water will be chemically stable in the distribution system and, under some circumstances, a lack of practical corrective measures for these problems. The problems cannot be classed as unique to the Navy, but are possibly aggravated by conditions that sometimes dictate the siting of military facilities in unfavorable locations. The response from the Southeast Division suggested development of a reliable means to predict and evaluate scale and corrosion in water systems. The extent of these problems seems to justify some effort in this direction.

CONCLUSIONS

1. Current naval station water-shortage problems are mainly at overseas island stations, and a total of 16 facilities currently must resort to expensive methods of water production or procurement.

2. Production costs at these stations generally fall into the range of $1.25 to $8.00 per thousand gallons, except that water at polar facilities is even more espensive.

3. Southern California is a geographic area that has an overall regional deficiency of water, but all mainland stations are reported to have adequate supplies for current and projected levels of activity. Several additional stations here would have to procure water from civil water agencies if their re ·irements doubled by 1980, but probably at a reasonable cost. It is not likely that on-station desalting will compete economically with purchased water. A similar situation may develop in other parts of the United States by the year 2000.

4. Minimum water costs for stations in deficiency regions in the United States will be achieved by maximum development and use of local supplies before procurement from regional civil agencies is undertaken.

5. Overseas water problems should be less severe in the future because of the commercial availability of electrodialysis and flash-distillation units.

6. Corrosion, scale, and deleterious mineral concentrations are water-quality problems that occur at many stations.

RECOMMENDATION

It is recommended that a further study be initiated to develop methods for improving the water quality at a number of naval shore stations, particularly with regard to its corrosiveness, which poses the most frequent quality problem.

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13. ABSTRACT

Present and predicted potable-water shortages at naval shore stations were surveyed to obtain information relating station water requirements to the growing national and worldwide concern over water availability. For this survey, a lack of conventional fresh-water sources and unreasonable costs for water procurement and production constitute a shortage. Current water problems were found to exist primarily at overseas facilities on small islands or in unfavorable coastal locations. Polar areas have a continuing water problem with high water-production costs, resulting in a number of subsidiary problems in polar-base operations. Within the continental United States, there are a number of large stations located in regions where overall water deficiencies are expected to occur by 1980 or 2000. The major problem areas are Southern California and the Texas southern Gulf Coast. A survey of water quality was also made, and corrosion, scale, and high concentrations of deleterious minerals were the most significant problems not responding to conventional treatment. It is recommended that a further study be initiated to develop improved methods for solving the water-quality problems.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Potable Water						
Shortage						
Survey						
Desalting						
Costs						

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